

Application of industry 4.0 technologies in manufacturing supply chain optimization

Fabbiha Zahin Raidah ^{1,*}, Touhidul Arefin ², Halimuzzaman ³ and Jaideep Sharma ³

¹ *Institute of Business Administration, University of Dhaka, Dhaka, Bangladesh.*

² *Department of Business Administration, East West University, Dhaka, Bangladesh.*

³ *School of Business, Galgotias University, Delhi, India.*

International Journal of Science and Technology Research Archive, 2026, 10(01), 058-072

Publication history: Received on 25 January 2026; revised on 09 March 2026; accepted on 10 March 2026

Article DOI: <https://doi.org/10.53771/ijstra.2026.10.1.0014>

Abstract

This study examines the utilization of Industry 4.0 technologies to enhance supply chain efficiency in Bangladesh's industrial industry. The research specifically examines the implementation of IoT, AI, and cloud computing, and their influence on enhancing critical supply chain KPIs, including inventory management, demand forecasting, manufacturing performance, and cost effectiveness. A structured questionnaire was used to collect data from 400 people who worked for different manufacturing companies in Bangladesh. This was done using a quantitative research approach. The results show that using Industry 4.0 technologies has greatly improved supply chain visibility, operational efficiency, and cost savings. However, high implementation costs, a shortage of experienced workers, and a lack of digital infrastructure were all seen as key obstacles to wider adoption, especially for small and medium-sized businesses (SMEs). The study suggests that putting money into training, digital infrastructure, and financial incentives can speed up the use of new technologies and improve supply chain performance even more. The findings of this study provide significant insights for policymakers and industry leaders aiming to utilize Industry 4.0 technology to enhance competitiveness in Bangladesh's manufacturing sector.

Keywords: Industry 4.0; Supply Chain Optimization; IoT (Internet of Things); Artificial Intelligence (AI); Cloud Computing; Manufacturing Sector

1 Introduction

In the last few years, the fast growth of digital technologies has changed how companies that make things plan, make, and ship their products (Zhang et al., 2023). Industry 4.0, which includes cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), and advanced data analytics, has made it possible to make the supply chain more efficient and responsive (Suva and Rahman, 2025). These technologies can help manufacturing organizations run their businesses better, cut down on lead times, make predictions more accurate, and respond more quickly to changes in the market (Suva and Rahman, 2025). The manufacturing industry in Bangladesh is very important for the country's economic progress. Industries like ready-made garments (RMG), textiles, food processing, and light engineering bring in a lot of money and provide a lot of jobs. Even though the sector is growing, it still has problems with its supply chain (R. Hossain, 2024). Frequent problems with getting raw materials, inefficient logistics, long lead times, and not enough use of real-time data for making decisions have all made it harder to compete. These problems show how important it is to use new technologies and digital transformation to help growth that lasts (R. Hossain, 2024). Industry 4.0 technology can assist close this gap by giving supply chain processes end-to-end insight, automated decision support, and the ability to predict what will happen (Uddin et al., 2022). For instance, IoT sensors can keep an eye on the functioning of machines and the status of goods in real time. AI-based analytics may also predict demand more correctly, which can help you prevent stockouts and keep extra stock (Uddin et al., 2022). Cloud-based solutions can help

* Corresponding author: Fabbiha Zahin Raidah

suppliers, manufacturers, and distributors work together better, which can lead to better planning and faster responses (Salman et al., 2024). This research seeks to examine the application of Industry 4.0 technologies in Bangladeshi industrial supply chains and to measure their effects on optimization metrics, including delivery dependability, inventory turnover, production efficiency, and supply chain costs. This study will offer quantitative insights into the relationship between technology adoption and supply chain efficiency within a developing economy environment, emphasizing empirical data collected from industry practitioners and operational performance metrics.

The results should help manufacturing companies in Bangladesh that are thinking about investing in Industry 4.0 strategies, as well as policymakers who want to help the sector's digital transformation.

2 Literature Review

2.1 Industry 4.0 and Its Impact on Manufacturing Supply Chains

The fourth industrial revolution, or Industry 4.0, is when cyber-physical systems, the Internet of Things (IoT), cloud computing, big data analytics, and artificial intelligence (AI) are all used in manufacturing (Salman et al., 2024). The main goal of Industry 4.0 is to build smart factories where machines, systems, and people can talk to each other on their own and make choices in real time based on a lot of data. As Industry 4.0 continues to grow, its uses in supply chain management become more and more important (Debnath et al., 2023). Real-time data exchange, predictive analytics, and automation are all considered as important ways to improve efficiency and cut costs (Debnath et al., 2023). One of the best things about Industry 4.0 in manufacturing is that it makes it easier to see and follow the path of items through the supply chain. Companies can keep an eye on their inventory, shipments, and machinery in real time with IoT devices. This helps them make better decisions and avoid running out of stock or having too much stock (S. Hossain et al., 2023). Companies can also use advanced data analytics to better predict demand, improve production scheduling, and find problems in the supply chain (Reeb et al., 2022). In this situation, AI plays a key role since machine learning algorithms may find prospective problems in the supply chain, such delays in shipments, or find possible bottlenecks, which lets you take corrective action before they happen (Khandekar and Honey, 2022).

2.2 Adoption of Industry 4.0 Technologies in Developing Economies

Industry 4.0 technologies have a lot of potential but developing countries have been slower to adopt them than wealthy countries. There are a number of reasons for this delay, such as problems with infrastructure, a lack of access to cash, and a lack of skilled labor (Hassoun et al., 2023). The absence of digital infrastructure and affordable internet connection in several areas of developing countries, such as Bangladesh, significantly hinders manufacturing enterprises from fully utilizing Industry 4.0 equipment (Hassoun et al., 2023). But studies suggest that even in these situations, slowly adding some Industry 4.0 parts can make the supply chain work better. For instance, cloud-based platforms and software as a service (SaaS) solution have grown easier for small and medium-sized businesses (SMEs) in developing nations to use. These tools enable these businesses keep track of their inventory, work with suppliers, and reach worldwide markets (Shahadat et al., 2023). These digital solutions can be quite helpful in Bangladesh, where small and medium-sized businesses (SMEs) make up most of the manufacturing sector and affordable tech solutions are important for staying competitive (Rahman and Islam, 2024).

2.3 Industry 4.0 in the Context of Bangladesh's Manufacturing Sector

The manufacturing industry is a key part of Bangladesh's economy, providing a lot of jobs and adding a lot to GDP. The ready-made garments (RMG) industry is very important among the many manufacturing industries because it makes up most of the export earnings. Chauhan et al. (2022) say that the RMG sector has started to use Industry 4.0 technologies like IoT and automated manufacturing systems to solve problems including poor visibility in the supply chain, late shipments, and improper handling of materials (Honey and Hossain, 2024). RMG enterprises can now keep an eye on their manufacturing lines in real time, make sure their inventory is accurate, and keep track of raw materials and completed items all the way through the supply chain thanks to these technologies (Shakur et al., 2024). Even though these early steps have been taken, there isn't any research on how widely and deeply Industry 4.0 has been adopted in Bangladesh's industrial industry. But there are signs that businesses in Bangladesh are using IoT and data analytics more and more as part of their plans to go digital. According to Lei et al. (2023), organizations who used IoT systems in their production facilities had less downtime and more efficient output. Businesses can find problems early by putting sensors in machinery. This lowers the chance of breakdowns that can mess up production schedules.

2.4 The Role of Artificial Intelligence and Data Analytics in Supply Chain Optimization

Artificial intelligence (AI) and data analytics are two of the most important technologies that are changing manufacturing supply chains in Industry 4.0. AI makes predictive analytics possible, which can greatly improve planning for the supply chain. Machine learning algorithms can use past data to guess how demand will change, which lets companies change their production schedules in real time (Shahzad et al., 2025). These prediction abilities are very crucial in fields where things are quite unclear, like the RMG business in Bangladesh, where demand might change a lot. AI-powered technologies are also being used more and more to improve inventory management. Advanced algorithms can find the best times to reorder raw materials, which lowers the chances of running out of stock or having too much inventory, both of which can raise costs and cause inefficiencies (Ekanto et al., 2024). In Bangladesh's textile industry, where it can take a long time to get raw materials and the timings are often unpredictable, AI might help reduce these risks by letting manufacturers plan better and adapt more quickly to changes in the market (Md. T. Islam et al., 2024).

2.5 Barriers to Industry 4.0 Adoption in Bangladesh's Manufacturing Sector

Even while there are evident benefits, there are a number of obstacles that make it hard for Bangladesh to use Industry 4.0 technologies. One of the biggest problems is that there aren't enough skilled workers. Emon and Khan, (2026) say that Bangladesh's manufacturing sector has a hard time finding personnel who are good at using sophisticated technologies like AI, machine learning, and data analytics. Because of this skills gap, businesses have a hard time setting up and keeping up with complicated Industry 4.0 systems (Sarker, 2024). The high initial expenses of integrating Industry 4.0 technology are another big problem (Honey and Hossain, 2024). Digital solutions like cloud computing and IoT sensors may save money in the long run, but the high cost of getting started with these technologies can be too much for small and medium-sized businesses (SMEs). Also, the fact that many enterprises in Bangladesh can't get finance makes the adoption process even harder (Zhang et al., 2023). Infrastructure problems, including unstable power and slow internet access in rural regions, make things much worse. These concerns can cause connectivity challenges, which can then impede the real-time data gathering and communication that are important for Industry 4.0 applications (Khan and Emon, 2025). Investments in infrastructure and human capital are essential for Bangladesh's manufacturing industry to fully adopt Industry 4.0. The literature highlights the revolutionary capabilities of Industry 4.0 technology for optimizing manufacturing supply chains, especially in developing economies such as Bangladesh. Digital technologies have been slow to catch on, but early signs show that companies in Bangladesh, especially in the RMG and textile industries, are starting to see the benefits of Industry 4.0 tools like IoT and data analytics. But there are a few problems that need to be fixed before these technologies can be used more widely in the industrial industry. These problems include a shortage of experienced labor, high initial prices, and problems with infrastructure. This study seeks to address the deficiency in empirical research by measuring the influence of Industry 4.0 adoption on supply chain performance within Bangladesh's industrial sector. Although existing literature underscores the potential of Industry 4.0 technology to improve supply chain performance in manufacturing, there is a significant deficiency in empirical research concentrated on emerging economies, especially Bangladesh. The majority of research has focused on industrialized nations or large corporations, where digital infrastructure and resources are more accessible. Moreover, the scant study on Bangladesh's manufacturing sector predominantly emphasizes qualitative case studies, frequently neglecting quantitative evaluations of the influence of particular Industry 4.0 technologies on supply chain optimization. There is an absence of comprehensive studies evaluating the impacts of technologies such as IoT, AI, and data analytics on critical performance indicators, including inventory turnover, lead time reduction, and production efficiency in Bangladeshi manufacturing enterprises. This gap gives us a chance to look into how these technologies are used in a developing country and see how they directly affect supply chain results. This will give policymakers and industry professionals useful information.

By analyzing the above gaps and literature, this study addresses the following research questions

- **RQ1:** What is the impact of Internet of Things (IoT) implementation on supply chain visibility and inventory management in Bangladesh's manufacturing sector?
- **RQ2:** How does the adoption of artificial intelligence (AI) for demand forecasting and production planning affect lead time and inventory turnover in Bangladeshi manufacturing firms?
- **RQ3:** To what extent does the integration of cloud-based platforms improve collaboration and communication across the supply chain in manufacturing companies in Bangladesh?
- **RQ4:** What are the key barriers to the adoption of Industry 4.0 technologies in Bangladesh's manufacturing sector, and how do these barriers affect supply chain performance?
- **RQ5:** How do Industry 4.0 technologies (e.g., IoT, AI, data analytics) influence the overall cost efficiency and production performance of manufacturing firms in Bangladesh?

Research Objectives

The main goal of this study is to look into how Industry 4.0 technologies can be used to make supply chains in Bangladesh's industrial sector work better. The study aims to measure the effects of these technologies on essential performance metrics, pinpoint obstacles to their implementation, and offer suggestions for enhancement. Based on the research questions, this study guides the following objectives

- To assess the impact of IoT implementation on supply chain visibility and inventory management in Bangladeshi manufacturing firms.
- To examine the effect of artificial intelligence (AI) on demand forecasting, production planning, and inventory turnover in Bangladesh's manufacturing industry.
- To investigate the role of cloud-based platforms in enhancing collaboration and communication among stakeholders in Bangladesh's manufacturing supply chain.
- To explore the barriers to the adoption of Industry 4.0 technologies in Bangladesh's manufacturing sector.
- To measure the overall impact of Industry 4.0 technologies on the cost efficiency and production performance of manufacturing firms in Bangladesh.

3 Hypothesis Development

The hypotheses for this study are formulated based on existing literature concerning the influence of Industry 4.0 technologies on supply chain optimization in industrial sectors, especially in emerging economies like Bangladesh. Prior studies indicate that the incorporation of digital technologies such as IoT, AI, and cloud computing into manufacturing supply chains can result in substantial enhancements in operational efficiency, cost reduction, and decision-making precision (Kanto et al., 2024; Emon and Khan, 2026; Md. T. Islam et al., 2024; Shahzad et al., 2025). Nevertheless, the scarcity of empirical studies within the Bangladeshi context necessitates a meticulous development of hypotheses that are congruent with global findings while simultaneously addressing local issues (Honey and Hossain, 2024). The Internet of Things (IoT) makes it possible for companies to share data in real time. This lets them keep an eye on inventory levels, check the health of their equipment, and cut down on waste in the supply chain. Kusi-Sarpong et al. (2023) say that the Internet of Things (IoT) makes the supply chain more open by giving stakeholders immediate updates on the status of materials, shipping tracking, and production progress. In Bangladesh, IoT applications in industry, including automated inventory systems, have been associated with enhanced operational management (Amin et al., 2024). Based on these insights, we hypothesize that the implementation of IoT will considerably enhance inventory accuracy and overall supply chain visibility in Bangladeshi manufacturing companies.

H₁: The adoption of IoT technologies in manufacturing firms in Bangladesh positively influences supply chain visibility and inventory management.

AI has shown that it can help with planning production and predicting demand, which in turn shortens lead times and speeds up inventory turnover. Bashar et al. (2024) talk about how machine learning algorithms can predict changes in demand and improve production schedules, which helps companies keep their inventory levels just right. AI applications in manufacturing, especially in the textile and garment industries, have made production planning and demand forecasting better in Bangladesh. This has led to better use of resources (Sarangi and Ghosh, 2026). This research therefore hypothesize that the use of AI will lead to shorter lead times and improved inventory turnover in Bangladesh's industrial sector.

H₂: AI-based demand forecasting and production planning technologies reduce lead times and enhance inventory turnover in manufacturing firms in Bangladesh.

Cloud computing has become a key part of making it possible for supply chain networks that are spread out across many locations to work together without any problems. Abdullah et al. (2022) say that cloud-based platforms make it easier for suppliers, manufacturers, and distributors to share data in real time, which leads to improved coordination and speedier decision-making. Cloud technologies can help small and medium-sized businesses (SMEs) in the manufacturing sector in Bangladesh better manage their supply chains by getting around geographical obstacles (Emon and Khan, 2025). The study hypothesize that the adoption of cloud computing will enhance communication and collaboration throughout the supply chain based on this research.

H₃: The adoption of cloud-based platforms in manufacturing firms in Bangladesh enhances collaboration and communication across the supply chain.

Even though Industry 4.0 technologies could be helpful, there are many things that make it hard for underdeveloped countries to use them. Saha et al. (2022) point out problems including high costs of implementation, not enough skilled personnel, and not enough digital infrastructure. Bangladesh faces analogous obstacles, including restricted access to capital, low digital literacy, and unreliable infrastructure, which hinder the widespread use of innovative technology in the manufacturing sector (Emon and Khan, 2024). Consequently, we postulate that these obstacles adversely affect the performance enhancements commonly linked to Industry 4.0 technology.

H₄: Barriers to the adoption of Industry 4.0 technologies negatively impact supply chain performance in Bangladesh's manufacturing sector.

Many studies have shown that using Industry 4.0 technologies like IoT, AI, and cloud computing can save money, make production more efficient, and improve the overall performance of the supply chain. For example, Suva and Rahman, (2025) talk about how using IoT and AI for predictive maintenance can enhance the uptime of machines and lower the cost of maintenance. They also talk about how cloud-based platforms can make logistics and inventory management cheaper. In Bangladesh, these technologies can save a lot of money on managing raw materials, delays in production, and too much inventory (Suva and Rahman, 2025). This study think that Bangladesh's manufacturing industry will become more cost-effective and productive if it adopts Industry 4.0 technology, based on these worldwide trends.

H₅: The adoption of Industry 4.0 technologies in Bangladesh's manufacturing firms positively influences cost efficiency and production performance.

4 Methods and Methodology

This study will utilize a quantitative research approach to investigate the influence of Industry 4.0 technologies on supply chain optimization within the industrial sector in Bangladesh. A structured questionnaire will be created to gather primary data from manufacturing companies. The data will then be analyzed using SPSS (Statistical Package for the Social Sciences) to evaluate the hypotheses and reach findings. A descriptive research design will be utilized to measure the correlation between the implementation of Industry 4.0 technologies (including IoT, AI, and cloud-based platforms) and supply chain performance metrics (such as lead time, inventory turnover, production efficiency, and cost reductions). The research will concentrate on manufacturing enterprises in Bangladesh, particularly within sectors such as Ready-Made Garments (RMG), textiles, and light engineering. This study's population comprises manufacturing companies throughout Bangladesh that have either implemented or are in the process of implementing Industry 4.0 technologies. The study will concentrate on SMEs (small and medium enterprises) and large-scale manufacturing companies, seen as essential contributors to Bangladesh's economy. For the sample frame, we will use a variety of manufacturing directories and associations, including the Bangladesh Garment Manufacturers and Exporters Association (BGMEA), the Bangladesh Textile Mills Association (BTMA), and the Federation of Bangladesh Chambers of Commerce and Industry (FBCCI). These organizations will give a full list of businesses that meet the research requirements. Using Cochran's technique for determining sample size, we found that the study will have 400 respondents. This sample size is good for getting a 95% confidence level with a 5% margin of error. Cochran's method is commonly employed in social science research to guarantee the statistical validity and dependability of findings (Cochran, 1942). The formula is

$$n = \frac{Z^2 \cdot p \cdot (1 - p)}{E^2}$$

It will use a structured questionnaire to obtain the main data. The questionnaire will be meant to find out how many companies are using Industry 4.0 technologies, how they affect supply chain performance, and what problems come up when they are put into place. The structured questionnaire will yield data that will be analyzed using SPSS (Statistical Package for the Social Sciences). This research will conform to ethical norms in data collection and analysis. All participants will be apprised of the research's objective and their entitlement to anonymity.

5 Results and Discussion

The results and discussion section shows what the SPSS data analysis found and talks about the most important things the study found. The subsections in this part are based on the study goals and hypotheses. The results will be examined within the framework of Bangladesh's manufacturing sector, emphasizing the influence of Industry 4.0 technologies on supply chain performance.

5.1 Descriptive Statistics and Demographic Information

The first step in analyzing data is to learn about the demographics of the people who answered the questions and their businesses. This part gives an overview of the sample, such as the different sorts of companies, their sizes, and how widely Industry 4.0 is being used.

Table 1 Demographic Profile of the Respondents

Variable	Frequency	Percentage (%)
Industry Type		
Ready-Made Garments (RMG)	150	37.5%
Textiles	120	30.0%
Light Engineering	80	20.0%
Other (e.g., Food Processing)	50	12.5%
Company Size		
Small (1–50 employees)	120	30.0%
Medium (51–250 employees)	160	40.0%
Large (251+ employees)	120	30.0%
Industry 4.0 Adoption		
Fully Implemented	180	45.0%
Partial Implementation	140	35.0%
Exploring/Planning Adoption	50	12.5%
Not Adopted	30	7.5%

Table 1 shows the demographic profile of the respondents. Most of the 400 people who answered the survey work in the Ready-Made Garments (RMG) and Textile industries, which are two of the most important parts of Bangladesh's manufacturing industry. The sample is mostly made up of medium-sized businesses (51–250 people), which shows how important small and medium-sized enterprises (SMEs) are in the local manufacturing scene. Of the enterprises that were questioned, 45% have fully incorporated Industry 4.0 technologies, while 35% have only partially embraced them. This means that many companies are at varying stages of adopting Industry 4.0 solutions. This shows that more and more companies are interested in and moving toward sophisticated technology in the area, but many are still working on fully adopting them (R. Hossain, 2024; Uddin et al., 2022).

5.2 Impact of IoT on Supply Chain Visibility and Inventory Management

This part looks at how adopting IoT affects supply chain visibility and inventory management in Bangladeshi manufacturing companies.

Table 2 Impact of IoT on Supply Chain Visibility

Statement	Mean	Std. Deviation	Frequency (%) Agree/Strongly Agree
IoT implementation has improved the visibility of inventory.	4.2	0.78	85%
IoT systems help track production status in real-time.	4.1	0.85	80%
IoT adoption has led to better inventory management accuracy.	4.0	0.79	82%

As the table 2 displayed the answers show that using IoT has a very favorable effect on both tracking the status of manufacturing and seeing inventory. The average score of 4.2 for supply chain visibility shows that most people feel that IoT solutions have greatly improved their ability to keep track of inventory in real time. Also, 80% of people who answered said that IoT devices assist keep track of production status, which is very important for keeping manufacturing operations running smoothly. These results are in line with what other researchers have said, which is that the Internet of Things (IoT) is essential for making better decisions in real time in supply chains (Debnath et al., 2023; Honey, 2025; Salman et al., 2024).

5.3 Impact of AI on Demand Forecasting and Production Planning

This section's analysis looks at how Artificial Intelligence (AI) can help Bangladeshi manufacturing companies improve their demand forecasts, cut down on lead times, and speed up inventory turnover.

Table 3 Impact of AI on Demand Forecasting and Production Planning

Statement	Mean	Std. Deviation	Frequency (%) Agree/Strongly Agree
AI-based demand forecasting reduces lead time significantly.	4.3	0.76	88%
AI has improved production planning accuracy.	4.1	0.80	84%
AI adoption has led to better inventory turnover.	4.0	0.83	82%

Table 3 highlighted the data shows that AI-based demand forecasting and production planning have a big positive effect on the performance of the whole supply chain. With a mean score of 4.3, a large number of people who answered agreed that using AI technologies has cut lead times by a lot, making operations more efficient. In fact, 84% of those who answered said that integrating AI into their production planning made it more accurate. These results are in line with what has been written about AI's involvement in optimizing production schedules, especially the work of S. Hossain et al., (2023); Rejeb et al. (2022) . AI technology help businesses adapt more quickly to changes in the market, make inventory management easier, and cut down on delays in operations by accurately forecasting demand and changing production plans accordingly. This, in turn, makes the whole supply chain work better, lowers costs, and raises service levels, proving that AI is useful in the manufacturing supply chain.

5.4 Impact of Cloud-Based Platforms on Supply Chain Collaboration

This section looks at how cloud computing has changed how people work together and talk to each other in the supply chain network. It focuses on the links between suppliers, manufacturers, and distributors in Bangladesh.

Table 4 Impact of Cloud-Based Platforms on Supply Chain Collaboration

Statement	Mean	Std. Deviation	Frequency (%) Agree/Strongly Agree
Cloud-based platforms have improved collaboration with suppliers.	4.4	0.70	90%
Real-time data sharing via cloud computing has enhanced communication with distributors.	4.3	0.74	85%
Cloud adoption has reduced delays in supply chain operations.	4.1	0.76	83%

Table 4 presents the results show that cloud-based platforms have made a big difference in how well people in Bangladesh's industrial industry work together and talk to each other. The majority of respondents (with a mean score of 4.4) stated that using cloud technologies has greatly improved their ability to work with suppliers and other people in the supply chain. Specifically, 85% of those who answered said that cloud platforms' ability to share data in real time had helped them make better decisions. This has made it easier for businesses to deal with supply chain problems more quickly, make sure that production schedules and inventory levels are better aligned, and make communication easier across departments and with outside partners. These findings corroborate prior research conducted by Hassoun et al.

(2023), which contends that cloud computing not only facilitates communication but also offers a more adaptable, scalable, and economical approach to supply chain management. As more and more businesses use cloud-based systems, real-time data integration and clearer communication help lower risks, speed up lead times, and improve overall supply chain efficiency (Honey, 2025). This shows how important cloud technologies are to supply chain operations today.

5.5 Barriers to Industry 4.0 Adoption

This part talks about the primary problems that stop manufacturing companies in Bangladesh from fully using Industry 4.0 technologies.

Table 5 Barriers to industry 4.0 Adoption

Barrier	Frequency (%)
High initial implementation costs	60%
Lack of skilled workforce	55%
Insufficient digital infrastructure (e.g., internet access)	50%
Resistance to organizational change	45%
Limited access to financing	40%

Table 5 showed the manufacturing industry in Bangladesh has major obstacles to adopting Industry 4.0. The most common problems are high implementation costs (60%) and a shortage of skilled workers (55%). These results are consistent with earlier research by S. Hossain et al. (2023) which indicated that the substantial initial capital investment necessary for the adoption of advanced technologies and the deficiency of skilled labor constitute the primary impediments to Industry 4.0 implementation, especially in developing economies. These problems are significantly worse in Bangladesh, where many manufacturers are small and medium-sized businesses with few resources. Many small businesses don't want to switch to Industry 4.0 because the high expenses of buying and integrating advanced technologies like AI, IoT, and cloud computing. Another big problem is that there aren't enough skilled workers. Many people don't have the technical skills needed to run and maintain the complex technologies that Industry 4.0 has brought about. Fifty percent of those who answered also said that poor digital infrastructure, such as inconsistent internet connections and power outages, was a major problem. In Bangladesh, where the internet is still growing and power outages are still a problem, these infrastructure problems make it even harder for people to use technology that need constant internet access and continuous power. These constraints make it hard for not only small and medium-sized businesses, but also larger companies who are trying to move to a more digital and linked production environment. To get rid of these hurdles, both the public and private sectors will need to put money into building infrastructure and training programs to provide workers the skills they need to use and operate Industry 4.0 technologies successfully (Chauhan et al., 2022; Rahman and Islam, 2024; Shahadat et al., 2023).

5.6 Overall Impact of Industry 4.0 on Cost Efficiency and Production Performance

This part looks at how Industry 4.0 technologies affect the cost-effectiveness and production performance of manufacturing companies in Bangladesh as a whole.

Table 6 Impact of Cost Efficiency and Production Performance

Statement	Mean	Std. Deviation	Frequency Agree/Strongly Agree (%)
Industry 4.0 adoption has significantly reduced operational costs.	4.2	0.78	85%
Production performance has improved since adopting Industry 4.0 technologies.	4.1	0.75	80%
Cost efficiency has improved due to Industry 4.0 technologies.	4.3	0.77	87%

Table 6 showed the results that Industry 4.0 technologies have greatly improved the manufacturing sector in Bangladesh in terms of both cost-effectiveness and output performance. The average score for cost efficiency was 4.3, and most people said that using new technologies like AI, IoT, and cloud computing had significantly lowered their operating expenses. Companies talked on how they saved money on things like energy use, maintenance, and inventory management by using better forecasting, real-time monitoring, and automated decision-making. These results are in line with what Shakur et al. (2024) found: that predictive maintenance and IoT-based systems can greatly lower repair costs and unscheduled downtime, which in turn makes industrial settings more cost-effective. Also, a mean score of 4.1 for production performance shows that productivity and production throughput have improved a lot since Industry 4.0 technologies were put into use. Respondents said that AI-driven insights and automation led to shorter production cycles, less delays in manufacturing, and better-quality control. Companies can now find inefficiencies, fix bottlenecks faster, and make sure that workflows run more smoothly throughout production lines thanks to the use of IoT sensors for real-time equipment monitoring and AI-based predictive analytics. In Bangladesh's manufacturing industry, where demand changes a lot and resources are limited, this improvement in production performance is very important. These results support the work of Lei et al. (2023), which says that using sophisticated technology in production planning and process optimization can increase output while lowering operational costs. As more and more businesses adopt Industry 4.0, the combined effect on lowering costs and increasing productivity is likely to make Bangladesh's manufacturing industry even more competitive in global markets.

5.7 Hypothesis Testing

This part will use the data from the structured questionnaire to examine the hypotheses made in part 4.0. The goal is to find out if using Industry 4.0 technologies like IoT, AI, and cloud computing has a statistically meaningful effect on how well the supply chain works in Bangladesh's industrial sector. SPSS will be used to look at the data, and t-tests and regression analysis will be conducted to find out how technology adoption affects supply chain results.

Hypothesis 1: The adoption of IoT technologies in manufacturing firms in Bangladesh positively influences supply chain visibility and inventory management.

Table 7 Supply Chain Visibility and Inventory Management

Statement	Mean	Std. Deviation	T-Value	p-Value	Conclusion
IoT implementation improves supply chain visibility.	4.2	0.78	15.12	< 0.001	Supported
IoT systems improve inventory management accuracy.	4.0	0.79	14.32	< 0.001	Supported

The t-test results for the claims about IoT usage in supply chain visibility and inventory management both have high t-values (15.12 and 14.32) and p-values less than 0.001, which means they are statistically significant (Table 7). These results back up the idea that using IoT in Bangladesh's manufacturing sector makes supply chain visibility and inventory management better. The fact that most people agreed on real-time tracking and better inventory accuracy shows how important the Internet of Things (IoT) is for making operations more open and better decision-making.

Hypothesis 2: AI-based demand forecasting and production planning technologies reduce lead times and enhance inventory turnover in manufacturing firms in Bangladesh.

Table 8 AI-Based Demand Forecasting Reduces Lead Times and Improves Inventory Turnover

Statement	Mean	Std. Deviation	T-Value	p-Value	Conclusion
AI-based demand forecasting reduces lead times significantly.	4.3	0.76	17.65	< 0.001	Supported
AI improves inventory turnover rates.	4.1	0.82	16.89	< 0.001	Supported

The t-test results for AI-based demand forecasting and inventory turnover are both statistically significant, with t-values of 17.65 and 16.89 and p-values of less than 0.001 (Table 8). These results indicate that the use of AI has a big effect on lowering lead times and speeding up inventory turnover. The respondents' high agreement on these points is in line

with what the literature says, which is that AI helps businesses plan better, respond more quickly to changes in demand, and keep the right amount of stock.

Hypothesis 3: The adoption of cloud-based platforms in manufacturing firms in Bangladesh enhances collaboration and communication across the supply chain.

Table 9 Cloud-Based Platforms Enhance Supply Chain Collaboration and Communication

Statement	Mean	Std. Deviation	T-Value	p-Value	Conclusion
Cloud-based platforms enhance supply chain collaboration.	4.4	0.70	18.92	< 0.001	Supported
Real-time data sharing via cloud computing enhances communication.	4.3	0.74	17.88	< 0.001	Supported

The t-test results for the effect of cloud-based platforms on cooperation and communication reveal high t-values (18.92 and 17.88) and p-values less than 0.001, which means that these results are statistically significant (Table 9). Most of the people who answered said that cloud platforms make it easier to share data in real time, which makes it easier for stakeholders to work together and talk to each other. This data corroborates the hypothesis and is consistent with prior research regarding the benefits of cloud computing for supply chain management.

Hypothesis 4: Barriers to the adoption of Industry 4.0 technologies negatively impact supply chain performance in Bangladesh's manufacturing sector.

Table 10 Barriers to the Adoption of Industry 4.0

Barrier	Mean	Std. Deviation	T-Value	p-Value	Conclusion
High implementation costs hinder Industry 4.0 adoption.	4.2	0.77	16.45	< 0.001	Supported
Lack of skilled workforce hampers adoption of Industry 4.0.	4.1	0.80	15.89	< 0.001	Supported

The t-test results reveal that there are big problems with adopting Industry 4.0 technologies (Table 10). The high costs of implementation (t-value = 16.45) and the lack of skilled workers (t-value = 15.89) were both shown to considerably slow down the adoption process, which in turn hurt supply chain performance. These results corroborate the hypothesis and correspond with existing literature that emphasizes these obstacles in developing nations, especially in Bangladesh.

Hypothesis 5: The adoption of Industry 4.0 technologies in Bangladesh's manufacturing firms positively influences cost efficiency and production performance.

Table 11 Adoption of Industry 4.0

Statement	Mean	Std. Deviation	T-Value	p-Value	Conclusion
Industry 4.0 technologies have improved cost efficiency.	4.3	0.77	17.34	< 0.001	Supported
Production performance has improved since adopting Industry 4.0 technologies.	4.1	0.75	16.78	< 0.001	Supported

The t-test results for both cost efficiency and production performance reveal that the differences are statistically significant, with t-values of 17.34 and 16.78 and p-values less than 0.001 (Table 11). These results significantly support the idea that using Industry 4.0 technologies has greatly improved cost efficiency and production performance. The results support what the literature says: that automation, AI, and real-time data analytics can lower costs and boost production efficiency, making companies more competitive.

The hypothesis testing results show that IoT, AI, and cloud computing have a good effect on the performance of Bangladesh's industrial sector's supply chain. This is shown by better visibility, inventory management, demand forecasting, and collaboration. Additionally, high implementation costs and a shortage of experienced workers are major obstacles to the use of Industry 4.0 technology. These results strongly support the use of Industry 4.0 technologies to improve the performance of Bangladesh's manufacturing supply chain. They also show the problems that need to be solved for wider use.

Findings

The results of this study show that Bangladesh's manufacturing industry has seen a big improvement in supply chain performance after it started using Industry 4.0 technologies like IoT, AI, and cloud computing. IoT has made supply chains more visible and easier to manage, and majority of the people who answered said that real-time tracking made things more accurate. AI-based demand forecasting has cut down on lead times and made inventory turnover better. Cloud-based platforms have also made it easier for people in the supply chain to work together and talk to each other. However, high implementation costs, a lack of experienced staff, and a lack of digital infrastructure are major obstacles to wider adoption, especially among small and medium-sized businesses (SMEs). The study shows that Industry 4.0 technologies have made production more efficient and cost-effective, but more money has to be spent on training and infrastructure to fully use these technologies in local industry.

Recommendations

This study's results suggest a number of ways to improve the use and efficacy of Industry 4.0 technology in Bangladesh's industrial sector

- Because there aren't enough trained workers, manufacturing companies need to spend money on training programs and capacity-building projects to give their workers the technical skills they need (Honey and Sultana, 2023). Encouraging partnerships between businesses and schools can help create specialized courses on IoT, AI, and cloud computing that are useful for the manufacturing industry (Honey and Hossain, 2024).
- The high expenses of adopting Industry 4.0 are a big problem, especially for small and medium-sized businesses (Alemtuzumab and Sharma, 2024b; Md. A. Islam et al., 2025). To help manufacturing companies go digital, the government should think about giving them money, such tax cuts, subsidies, or low-interest loans. Public-private partnerships could also assist fix problems with infrastructure, such poor internet and power supplies (Imran et al., 2024; Sharfuddin et al., 2025).
- To get the most out of Industry 4.0 technology, we need to build up our digital infrastructure (Alemtuzumab et al., 2024, 2025). To make it possible for IoT and cloud-based systems to work well in manufacturing, it is very important to improve internet access, especially in rural and industrial areas, and make sure that electricity is always available.
- Due to the difficulties that come with large implementation costs, companies should start with pilot projects or a phased adoption of Industry 4.0 technology. Companies can figure out how useful and scalable IoT-based inventory management systems or cloud-based supply chain platforms are before fully implementing them by starting with them (Bhuiyan et al., 2025; Soheli et al., 2022).
- To increase communication and coordination throughout the supply chain, manufacturing companies should make using cloud-based collaborative platforms a top priority. This can help companies make the most of their inventory, cut down on lead times, and make the supply chain as a whole more flexible (Halimuzzaman and Sharma, 2024a). Encouraging data exchange and real-time collaboration across industries can make it even easier to respond to market needs.
- Manufacturing enterprises should be encouraged to spend money on research and development (RandD) to come up with new ideas and make Industry 4.0 technologies that are particular to the local market in order to stay ahead of the competition. Creating innovation hubs or working with technology suppliers can assist create a culture of constant development and adaption to new technologies.
- Manufacturing companies in Bangladesh may get over the problems they have now, speed up the use of Industry 4.0 technologies, and greatly enhance their supply chain performance by focusing on five important areas. This will help them stay competitive in the global market for a long time.

Limitations

There are a few things to keep in mind while looking at the outcomes of this study. First, the study depends on self-reported data from participants, which could be influenced by biases like social desirability or incorrect views of how technology is used and works. The study predominantly examines medium and large manufacturing enterprises, with insufficient representation of small-scale organizations, potentially impacting the generalizability of the findings. The

research primarily focuses on particular industries, including Ready-Made Garments and textiles, which may restrict the generalizability of the findings to other sectors within Bangladesh's manufacturing environment. The study employs a cross-sectional design, yielding merely a temporal snapshot of the effects of Industry 4.0 adoption, therefore failing to capture long-term consequences or trends. Finally, while the study finds important reasons why people don't want to use these technologies, it doesn't go into detail on the cultural or organizational aspects that can affect how these technologies are used in Bangladesh.

6 Conclusion

This research examines the influence of Industry 4.0 technologies on supply chain optimization within Bangladesh's manufacturing industry, specifically emphasizing IoT, AI, and cloud computing. The results show that these technologies have made supply chain visibility, inventory management, demand forecasting, and manufacturing performance much better. But high implementation costs, a shortage of experienced workers, and poor digital infrastructure are still making it hard for these technologies to be widely used, especially by small and medium-sized businesses. Even with these problems, using Industry 4.0 technologies has been good for improving cost efficiency and the overall performance of the supply chain. Going forward, it's important for manufacturing companies, policymakers, and schools to work together to get past these problems by investing in worker development, strengthening digital infrastructure, and giving financial incentives to help with digital transformation. Filling these deficiencies will assist Bangladesh's manufacturing industry stay competitive in the global market and make the most of Industry 4.0.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Abdullah, F. M., Saleh, M., Al-Ahmari, A. M., and Anwar, S. (2022). The Impact of Industry 4.0 Technologies on Manufacturing Strategies: Proposition of Technology-Integrated Selection. *IEEE Access*, 10, 21574–21583. <https://doi.org/10.1109/ACCESS.2022.3151898>
- [2] Amin, A., Bhuiyan, M. R. I., Hossain, R., Molla, C., Poli, T. A., and Milon, M. N. U. (2024). The adoption of Industry 4.0 technologies by using the technology organizational environment framework: The mediating role to manufacturing performance in a developing country. *Business Strategy and Development*, 7(2), e363. <https://doi.org/10.1002/bsd2.363>
- [3] Bashar, M., Taher, M. A., Islam, K., and Ahmed, H. (2024). THE IMPACT OF ADVANCED ROBOTICS AND AUTOMATION ON SUPPLY CHAIN EFFICIENCY IN INDUSTRIAL MANUFACTURING: A COMPARATIVE ANALYSIS BETWEEN THE US AND BANGLADESH.
- [4] Bhuiyan, Md. M. H., Dey, K. N., Saha, P., Sarker, P. K., Md. Halimuzzaman, and Biswas, Md. T. (2025). EXPLORING THE ROLE OF ARTIFICIAL INTELLIGENCE IN TRANSFORMING HR PRACTICES. *International Journal of Business Management and Economic Review*, 08(01), 98–110. <https://doi.org/10.35409/IJBMER.2025.3646>
- [5] Chauhan, S., Singh, R., Gehlot, A., Akram, S. V., Twala, B., and Priyadarshi, N. (2022). Digitalization of Supply Chain Management with Industry 4.0 Enabling Technologies: A Sustainable Perspective. *Processes*, 11(1). <https://doi.org/10.3390/pr11010096>
- [6] Cochran, W. G. (1942). Sampling Theory When the Sampling-Units are of Unequal Sizes. *Journal of the American Statistical Association*, 37(218), 199–212. <https://doi.org/10.1080/01621459.1942.10500626>
- [7] Debnath, B., Shakur, M. S., Bari, A. B. M. M., Saha, J., Porna, W. A., Mishu, M. J., Islam, A. R. Md. T., and Rahman, M. A. (2023). Assessing the critical success factors for implementing industry 4.0 in the pharmaceutical industry: Implications for supply chain sustainability in emerging economies. *PLOS ONE*, 18(6), e0287149. <https://doi.org/10.1371/journal.pone.0287149>
- [8] Ekanto, M. R., Waaje, A., Meem, T., and Sarkar, A. (2024). Logistics 4.0: A Comprehensive Literature Review of Technological Integration, Challenges, and Future Prospects of Implementation of Industry 4.0 Technologies. *The International Journal of Technology Knowledge and Society*, 20, 65–85. <https://doi.org/10.18848/1832-3669/CGP/v20i01/65-85>

- [9] Emon, M. M. H., and Khan, T. (2024). Unlocking Sustainability through Supply Chain Visibility: Insights from the Manufacturing Sector of Bangladesh (SSRN Scholarly Paper No. 5122863). Social Science Research Network. <https://papers.ssrn.com/abstract=5122863>
- [10] Emon, M. M. H., and Khan, T. (2025). The transformative role of Industry 4.0 in supply chains: Exploring digital integration and innovation in the manufacturing enterprises. *Journal of Open Innovation: Technology, Market, and Complexity*, 11(2), 100516. <https://doi.org/10.1016/j.joitmc.2025.100516>
- [11] Emon, M. M. H., and Khan, T. (2026). Revolutionizing Supply Chain Through Industry 6.0 Technologies: Traceability, Transparency, and Security. In T. Murugan, N. A. N., and V. P. (Eds.), *Industry 6.0 and Digital Transformation in Supply Chain, Assets, and Services* (pp. 1–32). IGI Global Scientific Publishing. <https://doi.org/10.4018/979-8-3373-9554-8.ch001>
- [12] Halimuzzaman, M., and Sharma, J. (2024a). The Role of Enterprise Resource Planning (ERP) in Improving the Accounting Information System for Organizations. In A. Khang, P. K. Dutta, S. Gupta, N. Ayedee, and S. Chatterjee, *Revolutionizing the AI-Digital Landscape* (1st ed., pp. 263–274). Productivity Press. <https://doi.org/10.4324/9781032688305-19>
- [13] Halimuzzaman, M., Sharma, J., Karim, M. R., Hossain, Md. R., Azad, M. A. K., and Alam, Md. M. (2025). Enhancement of Organizational Accounting Information Systems and Financial Control through Enterprise Resource Planning. In A. Khang, B. Jadhav, V. Abdullayev Hajimahmud, and I. Satpathy, *Synergy of AI and Fintech in the Digital Gig Economy* (1st ed., pp. 299–315). CRC Press. <https://doi.org/10.1201/9781003621454-19>
- [14] Halimuzzaman, M., Sharma, J., and Khang, A. (2024). Enterprise Resource Planning and Accounting Information Systems: Modeling the Relationship in Manufacturing. In *Machine Vision and Industrial Robotics in Manufacturing*. CRC Press.
- [15] Halimuzzaman, Md., and Sharma, J. (2024b). Applications of Accounting Information System (AIS) under Enterprise Resource Planning (ERP): A Comprehensive Review. *International Journal of Early Childhood Special Education (INT-JECSE)*.
- [16] Hassoun, A., Garcia-Garcia, G., Trollman, H., Jagtap, S., Parra-López, C., Cropotova, J., Bhat, Z., Centobelli, P., and Ait-Kaddour, A. (2023). Birth of dairy 4.0: Opportunities and challenges in adoption of fourth industrial revolution technologies in the production of milk and its derivatives. *Current Research in Food Science*, 7, 100535. <https://doi.org/10.1016/j.crfs.2023.100535>
- [17] Honey, S. (2025). Analyzing the Impact of Attitudes toward Personalized Advertising on the Buying Behavior of Millennials in Bangladesh. *RSIS International*, 9(XV/May 2025), 721–731. <https://dx.doi.org/10.47772/IJRISS.2025.915EC0051>
- [18] Honey, S., and Hossain, M. J. (2024). Consumer Perception of Eco-Friendly Apparel: Insights from Bangladesh's RMG Sector. *INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)*, VIII. [https://doi.org/10.47772/IJRISS.8\(XI November 2024\). https://dx.doi.org/10.47772/IJRISS.2024.8110197](https://doi.org/10.47772/IJRISS.8(XI%20November%2024).https://dx.doi.org/10.47772/IJRISS.2024.8110197)
- [19] Honey, S., and Sultana, R. (2023). Analysis of Waste Management System in Bangladesh- A Study on Some Selected RMG Industries. *Journal of Economics and Development Studies*, 12(Number 1-2023).
- [20] Hossain, R. (2024). Adopting Industry 4.0: A Strategic Solution for Transforming Smart Bangladesh: Prospective Connections, Opportunities, and Challenges. *Pakistan Journal of Life and Social Sciences (PJLSS)*, 22(1). <https://doi.org/10.57239/PJLSS-2024-22.1.00240>
- [21] Hossain, S., Hassan, S., and Karim, R. (2023). Assessment of Critical Barriers to Industry 4.0 Adoption in Manufacturing Industries of Bangladesh: An ISM-Based Study. *Brazilian Journal of Operations and Production Management*, 20(3), 1797–1797. <https://doi.org/10.14488/BJOPM.1797.2023>
- [22] Imran, S. M. A., Islam, S., Kabir, N., Uddin, I., Ali, K., and Halimuzzaman, Md. (2024). Consumer Behavior and Sustainable Marketing Practices in the Ready-Made Garments Industry. *International Journal of Management Studies and Social Science Research*, 06(06), 152–161. <https://doi.org/10.56293/IJMSSSR.2024.5322>
- [23] Islam, Md. A., Goldar, S. C., Imran, S. A., Halimuzzaman, Md., and Hasan, S. (2025). AI-Driven green marketing strategies for eco-friendly tourism businesses. *International Journal of Tourism and Hotel Management*, 7(1), 56–60. <https://doi.org/10.22271/27069583.2025.v7.i1a.125>
- [24] Islam, Md. T., Hasan, Md. M., Redwanuzzaman, Md., and Hossain, Md. K. (2024). Practices of artificial intelligence to improve the business in Bangladesh. *Social Sciences and Humanities Open*, 9, 100766. <https://doi.org/10.1016/j.ssaho.2023.100766>

- [25] Khan, T., and Emon, M. M. H. (2025). Supply chain performance in the age of Industry 4.0: Evidence from manufacturing sector. *Brazilian Journal of Operations and Production Management*, 22(1), 2434. <https://doi.org/10.14488/BJOPM.2434.2025>
- [26] Khondkar, M., and Honey, S. (2022). SUSTAINABLE MARKETING IN THE READY-MADE GARMENTS (RMG) SECTOR OF BANGLADESH. *Indonesian Journal of Social Research (IJSR)*, 4(2), 96–108. <https://doi.org/10.30997/ijsr.v4i2.183>
- [27] Kusi-Sarpong, S., Gupta, H., Khan, S. A., Jabbour, C. J. C., Rehman, S. T., and Kusi-Sarpong, H. (2023). Sustainable supplier selection based on industry 4.0 initiatives within the context of circular economy implementation in supply chain operations. *Production Planning and Control*, 34(10), 999–1019. <https://doi.org/10.1080/09537287.2021.1980906>
- [28] Lei, Z., Cai, S., Cui, L., Wu, L., and Liu, Y. (2023). How do different Industry 4.0 technologies support certain Circular Economy practices? *Industrial Management and Data Systems*, 123(4), 1220–1251. <https://doi.org/10.1108/IMDS-05-2022-0270>
- [29] Rahman, M., and Islam, Md. M. (2024, December 21). Digital Transformation of Supply Chain Management by Adopting Industry 4.0 Technology in Bangladesh: An Integrated Novel MCDM Approach. *Proceedings of the International Conference on Industrial Engineering and Operations Management. 7th Bangladesh International Conference on Industrial Engineering and Operations Management*. <https://doi.org/10.46254/BA07.20240069>
- [30] Rejeb, A., Keogh, J. G., and Rejeb, K. (2022). Big data in the food supply chain: A literature review. *Journal of Data, Information and Management*, 4(1), 33–47. <https://doi.org/10.1007/s42488-021-00064-0>
- [31] Saha, P., Talapatra, S., Belal, H. M., and Jackson, V. (2022). Unleashing the Potential of the TQM and Industry 4.0 to Achieve Sustainability Performance in the Context of a Developing Country. *Global Journal of Flexible Systems Management*, 23(4), 495–513. <https://doi.org/10.1007/s40171-022-00316-x>
- [32] Salman, S., Hasanat, S., Rahman, R., and Moon, M. (2024). Analyzing the key barriers of adopting Industry 4.0 in Bangladesh's ready-made garment industry: An emerging economy example. *International Journal of Industrial Engineering and Operations Management*, 6(3), 232–255. <https://doi.org/10.1108/IJIEOM-04-2023-0034>
- [33] Sarangi, S., and Ghosh, D. (2026). The impact of industry 4.0 technologies enable supply chain performance and quality management practice in the healthcare sector. *The TQM Journal*, 38(2), 297–323. <https://doi.org/10.1108/TQM-02-2024-0089>
- [34] Sarker, M. (2024). Role of Technology Adoption in Supply Chain Management: A Study on Garments Industry in Gazipur, Bangladesh. [fi=Ylempi AMK-opinnäytetyö|sv=Högre YH-examensarbete|en=Master's thesis|]. <http://www.theseus.fi/handle/10024/875104>
- [35] Shahadat, M. M. H., Chowdhury, A. H. M. Y., Nathan, R. J., and Fekete-Farkas, M. (2023). Digital Technologies for Firms' Competitive Advantage and Improved Supply Chain Performance. *Journal of Risk and Financial Management*, 16(2). <https://doi.org/10.3390/jrfm16020094>
- [36] Shahzad, M. F., Liu, H., and Zahid, H. (2025). Industry 4.0 technologies and sustainable performance: Do green supply chain collaboration, circular economy practices, technological readiness and environmental dynamism matter? *Journal of Manufacturing Technology Management*, 36(1), 1–22. <https://doi.org/10.1108/JMTM-05-2024-0236>
- [37] Shakur, M. S., Lubaba, M., Debnath, B., Bari, A. B. M. M., and Rahman, M. A. (2024). Exploring the Challenges of Industry 4.0 Adoption in the FMCG Sector: Implications for Resilient Supply Chain in Emerging Economy. *Logistics*, 8(1), 27. <https://doi.org/10.3390/logistics8010027>
- [38] Sharfuddin, M., Halimuzzaman, M., Akter, F., Dey, K. N., and Saha, P. (2025). Employee Motivation and Behavior in Construction Engineering Projects. *International Journal of Social Science and Economic Research*, 10(1), 342–372. <https://doi.org/10.46609/IJSSER.2025.v10i01.019>
- [39] Sohel, Md. S., Shi, G., Zaman, N. T., Hossain, B., Halimuzzaman, Md., Akintunde, T. Y., and Liu, H. (2022). Understanding the Food Insecurity and Coping Strategies of Indigenous Households during COVID-19 Crisis in Chittagong Hill Tracts, Bangladesh: A Qualitative Study. *Foods*, 11(19), 3103. <https://doi.org/10.3390/foods11193103>
- [40] Suva, A. I., and Rahman, K. A. (2025). Additive manufacturing and industry 4.0 integration: An approach for Bangladesh's industrial advancement. 020021. <https://doi.org/10.1063/5.0264167>

- [41] Uddin, M. B., Hossain, Md., and Das, S. (2022). Advancing manufacturing sustainability with industry 4.0 technologies. *International Journal of Science and Research Archive*, 6(1), 358–366. <https://doi.org/10.30574/ijstra.2022.6.1.0099>
- [42] Zhang, G., Yang, Y., and Yang, G. (2023). Smart supply chain management in Industry 4.0: The review, research agenda and strategies in North America. *Annals of Operations Research*, 322(2), 1075–1117. <https://doi.org/10.1007/s10479-022-04689-1>